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Performance-Oriented Logistics Assessment (POLA): Relating Logistics Functional Capacities to Resources and Costs

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PREFACE

This document is one of four describing the Performance-Oriented Logistics Assessment (POLA) Project. The three companion documents are:

- *Performance-Oriented Logistics Assessment (POLA): Users' Manual for the Logistics Decision Model (LDM), Version IV*, R-3814-A, which explains the mechanics of using LDM, a PC-based theater campaign simulation model that plays a central role in the POLA methodology;
- *Performance-Oriented Logistics Assessment (POLA): Preparing the Logistics Decision Model (LDM) for Use in Analyses*, N-3393-A, which explains how to calibrate LDM and how to build its input files;
- *Performance-Oriented Logistics Assessment (POLA): Executive Summary*, R-3823-A, which provides an executive overview of the POLA methodology.

POLA was a project in RAND's Arroyo Center, sponsored by the DCSLOG Directorate of Plans and Operations (DALO-PLA). Its purpose was to develop a prototype methodology to help build the logistics portion of the Army five-year program.

By "prototype methodology," we mean a methodology that has been developed to the point that its usefulness has been demonstrated. That has been done: the Logistics Evaluation Agency (LEA) has adopted the prototype methodology, built a "shell" to link it with existing Army data files (such as the Total Army Equipment Distribution Plan, or TAEDP), and is using the combined system on real Army logistics problems. LEA calls the combined system Logistics Net Assessment (LNA). However, LNA is not yet a polished, user-friendly, fully supported system. Nor does it deal with all the logistics resources it might. Support of LNA and its further development are the responsibility of the Army.

This Note describes models and procedures other than LDM that are part of the POLA methodology. These models and procedures are used to estimate Combat Service Support (CSS) unit capacities from their equipment inventories, to estimate the costs of increasing those capacities by adding or replacing equipment, and to construct cases for analysis. The combat performance for each case can then be assessed by LDM. This Note also identifies the Army data sources that support these models and procedures. It will be of interest both to users of the LNA system and to those who must periodically recalibrate the system for use in subsequent analyses.

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Army Regulation 5-21 contains basic policy for the conduct of the Arroyo Center. The Army provides continuing guidance and oversight through the Arroyo Center Policy Committee (ACPC), which is co-chaired by the Vice Chief of Staff and by the Assistant Secretary for Research, Development, and Acquisition. Arroyo Center work is performed under contract MDA903-91-C-0006.

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Lynn E. Davis is Vice President for the Army Research Division and Director of the Arroyo Center. Those interested in further information about the Arroyo Center should contact her office directly:

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SUMMARY

THE PERFORMANCE-ORIENTED LOGISTICS ASSESSMENT (POLA) PROJECT

POLA was intended to develop a prototype methodology to help build the logistics portion of the Army five-year program. When building its program, the Army first estimates a requirement for each resource, but the price of satisfying all requirements always greatly exceeds the amount the Army can spend. Thus, the Army must next decide how much of each requirement not to satisfy. The Army has always made these decisions on somewhat arbitrary grounds, for it has never succeeded in developing tools that would systematically rate different resources, intended to support disparate functions, on common scales.

The POLA methodology attempts to rectify this lack of estimating effects on combat performance of alternative investments in logistics resources. Combat performance is measured in terms of forward line of troops (FLOT) movement, Red and Blue weapons engaged and attrited, and Red and Blue resources consumed and personnel lost. Logistics resources considered include stocks of ammunition, petroleum, oil, and lubricants (POL), war reserve equipment, and replacement personnel. Also considered are resources that increase Combat Service Support (CSS) capacities, such as capacities to handle ammunition, transport dry cargo, etc.

THE POLA METHODOLOGY

As illustrated in Fig. S.1, the POLA methodology has been implemented as a "tool kit" of many small models, rather than as a single comprehensive model. The Logistics Decision Model (LDM) is a central component. LDM estimates the effects of logistics improvements on combat performance. It simulates the ways that Red and Blue combat forces are influenced by CSS capacities (e.g., transportation, ammunition handling, maintenance) and logistics resources (e.g., stocks of ammunition, war reserve equipment, replacement personnel).

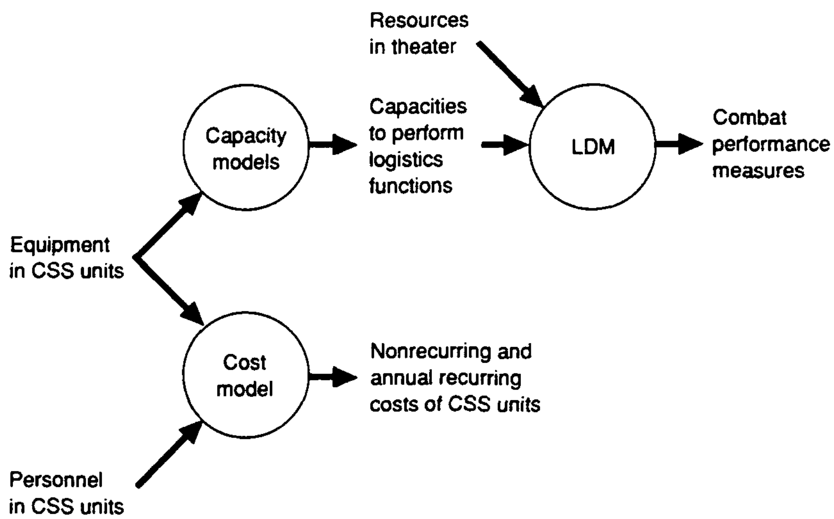

Fig. S.1—Overview of the POLA Methodology

By itself, LDM cannot do all that is required of the POLA methodology. It can estimate the effect on combat performance of varying the capacities to perform certain logistics functions, such as ammunition or POL handling, but those capacities must themselves be estimated from physical resources. In addition, dollar costs of these resources must be estimated. Finally, cases for analysis must be built. This Note discusses the supporting models and procedures needed to accomplish these tasks.

ESTIMATING UNIT CAPACITIES

The capacity of a CSS unit to perform its primary task will depend on the equipment items on hand and their status, the personnel on hand and their status, and environmental factors such as enemy action and support from friendly forces. However, we do not consider the possible effects of environmental factors, and we assume that by the time the

unit deploys, its complement of personnel has been rounded out and fully trained, and that all available equipment has been brought to operational status. Thus, our method estimates only how the unit's capacity depends on the equipment inventories on hand.

Our method is adapted from AR 220-1 [1]. We identify the items of equipment that are critical for performing the unit's primary task. AR 220-1 identifies items with an Equipment Readiness Code (ERC) of A or P[1] as critical, but we sometimes choose a somewhat different list. For each critical item, we form the ratio of the on-hand to the required quantities. Then we calculate the unit's capacity as the minimum of the ratios, multiplied by the capacity it is designed to have when all of its personnel and equipment requirements are filled. This is a simplification of the method discussed in AR 220-1; it allows one to disregard the ten percent of the ERC A items with the lowest ratios.

Our simplified method yields no more than an approximation of a unit's capacity. For many units, this approximation is very crude. For example, a unit may need night-vision goggles for nighttime operations but not for operations in daylight. Thus night-vision goggles contribute to at most half of the capacity. Or, one equipment item can often be substituted for another--for example, two 10,000-gallon storage bags for a single 20,000-gallon bag. The substitutable items should be combined into "equivalence classes" before the unit's capacity is calculated.

Our simplified method can be adapted to account for peculiarities such as these, and we think these adaptations will yield better estimates of capacity than the direct application of the simplified method. Nevertheless, the approximations remain rough. Detailed simulations or actual field exercises would be needed to develop more

[1]The Table of Organization and Equipment (TOE) for a unit contains the ERC for each equipment item. Equipment items coded ERC A (Primary Weapons and Equipment) are employed directly in the accomplishment of assigned operational missions and tasks. Equipment items coded ERC P (Pacing Items) are items to which the capacity of the unit is particularly sensitive. The A57 TOE Edit File contains computer-readable listings of all Tables of Organization and Equipment. It is available from Headquarters TRADOC (ATCD-OA), Ft. Monroe, VA 23651.

sophisticated and accurate methods. In their absence, however, one must rely on simple approximations.

ESTIMATING COSTS OF LOGISTICS IMPROVEMENTS

The Cost Model

We use a very simple cost model for estimating the costs of logistics improvements to CSS units. It estimates the nonrecurring and annual recurring costs of acquiring, maintaining, and operating an active Army unit[2] (or collection of units) in peacetime. Nonrecurring costs include procurement of the unit's equipment plus extra equipment to serve as operational readiness and repair cycle floats, initial procurement of spares and repair parts for both the unit and central supply, initial training of personnel, etc. Annual recurring costs include replenishment spares and repair parts, military pay and allowances for the unit's personnel, a share of depot maintenance costs, etc.

The cost model requires seven inputs.

- Aircraft procurement cost;
- Missile procurement cost;
- Wheeled and tracked combat vehicles procurement cost;
- Other equipment procurement cost;
- Equipment weight;
- Number of officers plus warrant officers; and
- Number of enlisted personnel.

[2] There are currently no versions of this model for National Guard or Army Reserve units. However, the Arroyo Center has undertaken to produce such versions.

To prepare these inputs, we extract data from the Total Army Equipment Distribution Program (TAEDP),[3] the Army Master Data File (AMDF),[4] and the Force Accounting System (FAS).[5]

The cost model estimates dozens of *cost elements*, mostly by multiplying one or more of the inputs by a *cost factor*. For example, military pay and allowances for officers (a cost element) are the product of the annual pay per officer (a cost factor) multiplied by the number of officers (an input). The factors and estimating relations are based on historical data and may be invalidated by changes in how the Army does its day-to-day business (e.g., increased reliance on training with simulators or a reduced frequency of overhauls on major equipment items). Thus, the factors and relations should be periodically reexamined and updated.

Estimating the Cost of Logistics Improvements

We use this model to estimate the incremental cost of improvements to CSS units. We apply the model before a unit receives a logistics improvement and again afterwards. The cost of the improvement is the difference between the "before" and "after" cost estimates.

If the improvement consists of replacing old kinds of equipment with new kinds (e.g., an old type of forklift with a new, more capable one), the nonrecurring cost of the displaced equipment must be treated as "sunk." It cannot be used to offset the costs associated with the new equipment. But if the displaced equipment is transferred to other units, they will not incur the "sunk" cost. The cost model should be applied to the entire collection of units affected by the improvement, including those that receive the displaced equipment.

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[3]The functional proponent of the TAEDP is the DCSLOG Equipment and Readiness Division (DALO-SMD), Pentagon. The files themselves are maintained at Depot Systems Command, Chambersburg, PA 17201.

[4]The AMDF can be obtained from the U.S. Army Materiel Command's Catalogue Data Activity, New Cumberland Army Depot, New Cumberland, PA 17070-5010.

[5]The FAS is the responsibility of the DSCOPS Directorate of Operations, Readiness, and Mobilization (DAMO-OD), Pentagon.

A separate "before" versus "after" difference can be calculated for each cost element, and these differences can be summarized and presented in any desired way. Sometimes it is useful to present a single cost index that can be used for quick comparisons of alternatives, such as life-cycle cost, defined as the total nonrecurring cost plus a specified number of years' worth of the total annual recurring cost (the Army often uses 20 years). It would be useful to spread the estimated cost elements over fiscal years to provide estimates of the effect of a proposed logistics improvement on the Army's budget, but this is not possible with the current version of the model.[6]

DEFINING CASES FOR ANALYSIS

Identify CSS Units in the Analysis

One must first identify the CSS units to be considered in the analysis. These will be the units that deploy to the theater of operations in the scenario used for the analysis and that perform logistics functions represented in LDM. A useful data source is the "M" Force, an extract from the FAS that lists all the units in the Army.

Describe Each Unit

Second, one must describe each unit identified, both as it appears initially and as it may appear once it receives a logistics improvement. The description of a unit in either its initial or improved state must include the inputs needed by both LDM (capacity and arrival date in theater) and the cost model (see above). Of course, the user should also keep track of the individual equipment items added to or displaced from each unit to improve it.

[6] The Arroyo Center has undertaken to produce such a version. It will impose on the user the added burden of specifying a schedule for making the improvement--that is, year by year, how many new equipment items and personnel would be added to the unit and how many old equipment items and personnel retired.

Construct Analysis Cases

Finally, one must combine the unit descriptions into overall analysis cases. To construct a case, we select a subset of units to improve and leave the remaining units in their initial, unimproved states. In any analysis, there will be dozens of units, and the number of different subsets--and hence the possible number of cases--is astronomical. We suggest the following scheme for generating a starting set of interesting cases. More cases can be added, if the course of the analysis suggests they will be useful.

We construct a separate sequence of cases for each LDM capacity parameter for which we have identified units. Each sequence begins with a base case, in which all units appear in their initial, unimproved states. To form the rest of the sequence, we sort the units corresponding to the chosen LDM capacity parameter according to their time of arrival in the theater, breaking ties according to the cost per unit of capacity added. The first excursion case will improve only the first unit, the second case will improve the first and second units, and so on. Throughout the sequence, all units that do not correspond to the chosen LDM capacity parameter will remain in their initial, unimproved states. The LDM cases in the sequence successively increase the chosen LDM capacity parameter, while holding all other capacity parameters at their base case values.

A more elaborate method for defining cases would be required if we improve units by replacing their old equipment with new, more capable types, and give the displaced equipment to other units considered in the analysis. In particular, we would need a scheme for distributing displaced equipment to other units. In principle, such a scheme could also redistribute the equipment that the units possess in their initial, unimproved states. It is possible that this could increase overall logistics functional capacities at zero overall cost to the Army.

ACKNOWLEDGMENTS

The authors are grateful to the following people for their contributions.

- The Operations Research and Systems Analysis (ORSA) Support Team at the Logistics Evaluation Agency (LEA) uncovered errors and suggested numerous improvements in early versions of the POLA methodology. They have incorporated the latest versions of the models in their Logistics Net Assessment system.
- Karl Hoffmayer of RAND reviewed this Note and made many helpful suggestions for its improvement.
- Irene Gordon prepared the manuscript for publication.

CONTENTS

FIGURE

TABLES

GLOSSARY

ADCCO	Army Deployment Control Code
AFPCH	Army Force Planning Cost Handbook
AMDF	Army Master Data File
AR	Army Regulation
ASIOE	Associated Support Items of Equipment
CAA	Concepts Analysis Agency
COMMZ	Communications Zone
CSA	Corps Support Area
CSS	Combat Service Support
DALO-PLA	Department of the Army, Deputy Chief of Staff for Logistics, Directorate of Plans and Operations
DCSLOG	Deputy Chief of Staff for Logistics
DOS	Disk Operating System
DS	Direct Support (see also GS)
ERC	Equipment Readiness Code
FAS	Force Accounting System
FASTALS	Force Analysis Simulation of Theater Administrative and Logistics Support
FLOT	Forward Line of Troops
GS	General Support (see also DS)
LAD	Latest Arrival Date
LDM	Logistics Decision Model
LEA	Logistics Evaluation Agency
LIN	Line Item Number

LNA	Logistics Net Assessment
LR^3	Logistics Readiness Rating Report
MOS	Military Occupational Specialty
MPA	Military Pay and Allowances
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological, and Chemical
OMA	Operations and Maintenance, Army
ORSA	Operations Research and Systems Analysis
PC	Personal Computer (see DOS)
PCS	Permanent Change of Station
PLL	Prescribed Load List
POL	Petroleum, Oil, and Lubricants
POLA	Performance-Oriented Logistics Assessment
Program 2	The General Forces part of the Army Five-Year Program
Program 7M	The Depot Maintenance part of the Army Five-Year Program
Program 7S	The Central Supply part of the Army Five-Year Program
Program 8M	The Medical part of the Army Five-Year Program
Program 8T	The Training part of the Army Five-Year Program
Program 8O	The Other Personnel part of the Army Five-Year Program
RCZ	Rear Corps Zone
SRC	Standard Requirements Code
TAEDP	Total Army Equipment Distribution Program
TIME_PHASE	One of the types of input files required by LDM
TMDE	Test, Measurement, and Diagnostic Equipment
TMT	Transportation Medium Truck
TOE	Table of Organization and Equipment

TSA	Theater Storage Area
UIC	Unit Identification Code
WTCV	Wheeled and Tracked Combat Vehicles

I. INTRODUCTION

This document is one of four describing the Performance-Oriented Logistics Assessment (POLA) project. Sponsored by the Deputy Chief of Staff for Logistics (DSCLOG), Directorate of Plans and Operations (DALO-PLA), this project has developed a prototype methodology to help build the logistics portion of the Army five-year program. The methodology consists of a central component, the Logistics Decision Model (LDM) [2,3], and a number of supporting models and procedures. This Note discusses the supporting models and procedures--the estimation of Combat Service Support (CSS) unit capacities from their equipment inventories, the estimation of the costs of increasing those capacities by adding or replacing equipment, and the construction of cases for analysis.

THE PERFORMANCE-ORIENTED LOGISTICS ASSESSMENT (POLA) PROJECT

The overall POLA project is described in a companion publication [4], but to provide context we summarize it here. POLA was intended to develop a prototype methodology to help build the logistics portion of the Army five-year program. When building its program, the Army first estimates a requirement for each resource, but the price of satisfying all requirements always greatly exceeds the amount the Army can spend. Thus, the Army must next decide how much of each requirement not to satisfy. The Army has always made these decisions on somewhat arbitrary grounds, for it has never succeeded in developing tools that would systematically rate different resources, intended to support disparate functions, on common scales.

The POLA methodology attempts to rectify this lack by estimating effects on combat performance of alternative investments in logistics resources. Combat performance measures thus become the common scales on which different resources are rated. If an increment of one resource has relatively little impact on combat performance, and an equal-cost increment of a second resource has a large impact, the Army may prefer

to satisfy less of the requirement for the first resource and more of the requirement for the second. Combat performance is measured in terms of forward line of troops (FLOT) movement, Red and Blue weapons engaged and attrited, and Red and Blue resources consumed and personnel lost. Logistics resources considered include stocks of ammunition, petroleum, oil, and lubricants (POL), war reserve equipment, and replacement personnel. Also considered are resources that increase CSS capacities such as capacities to handle ammunition, transport dry cargo, etc.

THE POLA METHODOLOGY

The Logistics Decision Model (LDM)

The POLA methodology has been implemented as a "tool kit" of many small models, rather than as a single comprehensive model. The Logistics Decision Model is a central component. LDM estimates the effects of logistics improvements on combat performance. It simulates the ways that Red and Blue combat forces are influenced by CSS capacities (e.g., transportation, ammunition handling, maintenance) and logistics resources (e.g., stocks of ammunition, war reserve equipment, replacement personnel).

In LDM, the user represents logistics improvements as changes in capacities or available resources from a base case. By comparing a logistics improvement case with the base case, he can estimate the effects of the logistics changes on combat performance measures. The user can also observe indicators of logistics "health," such as maintenance queues that have built up, vehicles abandoned for lack of recovery assets, excess capacities, etc.

Other POLA Methodology Components

By itself, LDM cannot do all that is required of the POLA methodology. It can estimate the effect on combat performance of varying the capacities to perform certain logistics functions, such as ammunition or POL handling, but those capacities must themselves be estimated from physical resources. For example, the handling capacity of a direct support (DS) Ordnance Company must be estimated from the numbers of its forklifts and cranes.

One must also estimate the dollar costs of these resources. The cost-estimating procedures must estimate much more than the current purchase price of a particular resource. Buying a resource (e.g., a variable reach forklift) commits the Army to a number of other expenditures as well (e.g., costs for training of crews and maintenance personnel, for fuel, and for storage facilities). The procedures must estimate the overall cost of equipping and fielding a new unit, or this can be applied to incremental resources to estimate the cost of adding resources and/or people to an existing unit.

It is also necessary to build cases for analysis. A *base case* should be singled out that reflects the Army as it is programmed to appear in the analysis year (the current year or a specified future year). Excursion cases are constructed by adding selected kinds and amounts of logistics improvements to the base case. We have identified Army data bases that describe the current Army and the Army that is currently programmed for the future, and we have worked out procedures for drawing from them the unit and resource data we need to describe the analysis cases. Most important among these data bases are:

- TOEs (Tables of Organization and Equipment);[1]
- TAEDP (Total Army Equipment Distribution Program);[2]
- AMDF (Army Master Data File);[3] and
- FAS (Force Accounting System).[4]

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[1]The A57 TOE Edit File contains computer readable listings of all Tables of Organization and Equipment. It is available from Headquarters TRADOC (ATCD-OA), Ft. Monroe, VA 23651.

[2]The functional proponent of the TAEDP is the DCSLOG Equipment and Readiness Division (DALO-SMD), Pentagon. The files themselves are maintained at Depot Systems Command, Chambersburg, PA 17201.

[3]The AMDF can be obtained from the U.S. Army Materiel Command's Catalogue Data Activity, New Cumberland Army Depot, New Cumberland, PA 17070-5010.

[4]The FAS is the responsibility of the DSCOPS Directorate of Operations, Readiness, and Mobilization (DAMO-OD), Pentagon.

LOGISTICS NET ASSESSMENT

The methodology developed by the POLA project has been adopted by the U.S. Army Logistics Evaluation Agency (LEA). The Operations Research and Systems Analysis (ORSA) Support Team at LEA is responsible for further development and implementation of methodology, for maintaining data files, and for periodically recalibrating LDM and providing it to action officers in the Pentagon. They have created a Logistics Net Assessment (LNA) system that consists of:

- An input processor, written as a dBAse III application;
- The LDM program;
- An output analyzer, in the form of Lotus 1-2-3 spreadsheets with macros; and
- A graph generator, which uses Lotus Graph Writer.

These modules are integrated through the use of DOS batch files. Users interested in obtaining the entire LNA system should contact the ORSA Support Team at LEA.

ORGANIZATION OF THIS NOTE

This Note describes the non-LDM methodology components of POLA. Section II discusses methods for estimating the capacities of CSS units to perform their primary tasks. These capacities are estimated from the inventories of selected equipment items each unit possesses. Section III describes a model and procedure for estimating the cost of improving the capacity of a CSS unit, either by adding equipment or by replacing old equipment items with new, more capable ones. Section IV presents a systematic approach to defining analysis cases. The combat performance and cost for each case, as compared with the base case, can then be assessed by LDM and the cost model, respectively.

II. ESTIMATING UNIT CAPACITIES

In this section, we discuss the problem of estimating the capacity of a CSS unit to perform its primary task. In the most general case, a unit's capacity will depend on many factors, including the equipment items on hand and their status, the personnel on hand and their status, and such environmental factors as temperature (e.g., arctic versus desert conditions), enemy action (e.g., NBC conditions), and support from friendly forces (e.g., supplies of POL, maintenance support). We will not, however, consider the effects of environmental factors. In addition, we will assume that by the time the unit deploys, its complement of personnel has been rounded out and fully trained, and that all available equipment has been brought to operational status. Thus, we will only estimate how the unit's capacity depends on the inventories of equipment on hand.

We first describe a general method for estimating how a unit's capacity depends on its equipment on hand. Then, we will examine particular kinds of CSS units to illustrate some shortcomings of this method and how they may be overcome.

A GENERAL METHOD FOR CALCULATING CAPACITIES

In AR 220-1 [1] the Army describes a method for estimating the readiness rating of any type of unit. One component of overall readiness, called logistics readiness, is estimated from inventories of equipment on hand. We have adapted the calculation of logistics readiness so that it produces an estimate of unit capacity.

First, we determine the design capacity of the unit--that is, the capacity it would have if it possessed all the equipment and personnel it is required to have. This will be stated in the field manual that describes the unit, and also in the narrative portion of the unit's TOE (see footnote 1, p.3).

Next, we identify the items of equipment that are critical for performing the unit's primary task. According to AR 220-1, the critical items will be those with Equipment Readiness Codes (ERC) A or P.[1] However, we sometimes choose a somewhat different list, including at least the pacing items and often some of the ERC A items as well. Advice from persons with experience in a particular kind of unit should help one choose a reasonable list.

The unit has a required quantity and a quantity on hand of each critical item. The quantity on hand can be found in the TAEDP. The required quantity can be found in the TOE, if one is content to deal with model units, or it can be found in the TAEDP (for the subset of TOE items found there) if one deals with real units.

For each critical item, we form the ratio of the on-hand and required quantities. Then we calculate the unit's capacity as the minimum of the ratios, multiplied by the capacity it is designed to have when all of its personnel and equipment requirements are filled. In mathematical terms, we describe this method as follows. Let

DES = design capacity of the unit

CRIT = set of critical items

OH_i = on-hand quantity of item i (both ERC A and ERC P items)

RQR_i = required quantity of item i (both ERC A and ERC P items)

Then CAP, the actual capacity of the unit, may be calculated as:

$$(2.1) \qquad FILL_i = OH_i/RQR_i$$

$$(2.2) \qquad FILL\_CR = Min\{ FILL_i \mid i \in CRIT \}$$

[1]The ERC is one of the data elements given in the TOE. Equipment items coded ERC A (Primary Weapons and Equipment) are employed directly in the accomplishment of assigned operational missions and tasks, so shortages of these items should significantly affect the unit's capacity. Equipment items coded ERC P (Pacing Items) are items to which the capacity of the unit is particularly sensitive.

(2.3) CAP = DES * FILL_CR

This is a simplification of the method discussed in AR 220-1, which allows one to disregard the ten percent of the ERC A items with the lowest ratios.

SHORTCOMINGS OF THE GENERAL METHOD

The general method yields no more than an approximation of a unit's capacity. For many units, this approximation is very crude. For example, it assumes that every equipment item is either a potential "show stopper," whose absence will reduce the unit's capacity to zero, or it will have no effect on the unit's capacity. Equipment items often have effects on the unit's capacity between these two extremes. For example, the primary task of a unit may have to be performed under a variety of circumstances, and different equipment may be needed in different circumstances. Thus, the unit may need night-vision goggles to operate at night but not in daylight. The capacity of the unit should depend less strongly on equipment needed in only some circumstances than it does on equipment that is always needed.

One equipment item in a unit can often be fully or partially substituted for another. Thus a unit may have two different pumps, or two different size storage tanks, or two forklifts with different capacities, or both forklifts and cranes. The substitutable items should somehow be combined into "equivalence classes" before the unit's capacity is calculated.

An item of equipment may depend on others for support (these other items are its Associated Support Items of Equipment, or ASIOE). But the performance of the primary item may only degrade gradually if its ASIOE are not available. Certain tool sets for performing maintenance may fall in this category. If one places the primary item on the critical items list, should one also put its ASIOE on the list?

Finally, a unit will have many tasks. One is its primary task, but the others must also be performed. For example, a DS Ordnance Company has the primary task of "establishing and operating an ammunition supply facility for the receipt, storage, rewarehousing, and issue of conventional ammunition." Its other tasks, including unit moves, unit defense, communication and other headquarters functions, and housekeeping functions, contribute indirectly to the performance of the primary task. For example, the unit must be able to move to remain near the units it provides with ammunition, since those units are expected to move frequently. Thus, equipment that contributes to the unit's capability to perform these other tasks indirectly affects its capacity to perform the primary task. Shortages of this equipment will generally have a smaller effect on the unit's capacity than proportionate shortages of equipment necessary to perform the primary task.

ADAPTING THE GENERAL MODEL TO UNIT PECULIARITIES

In the subsections that follow, we examine a number of different kinds of units and show how the general method can be adapted to their peculiarities. The examples given here do not exhaust all the ways one might adapt the general method. Other kinds of units might require kinds of adaptations not shown here.

We think these adaptations will yield better estimates of capacity than the direct application of the general method, but they are nevertheless still rather rough approximations. Detailed simulations or actual field exercises would be needed to develop more sophisticated and accurate methods. These more sophisticated methods do not now exist for most types of units, and there is no prospect that they will be developed soon. For the present, therefore, one must rely on simple approximations such as those described here.

Transportation Medium Truck (TMT) Companies

The general method works better for truck companies than it does for most other CSS unit types. Table 2.1 shows the critical items for Theater TMT Cargo Companies.[2] These items, tractors and trailers, are the only items coded ERC P (Pacing Items) in the TOEs. The entries in the table are the required quantities of the named equipment items.

In these units, many other line item numbers (LINs) are coded ERC A. These include radios, gas masks, 3/4-ton trucks, generators, outdoor lighting sets, and various kinds of maintenance tools and kits. A case can be made that, if the unit lacks these equipment items, its capacity will degrade over time. Clearly, however, a shortage of these items will not have the immediate or profound impact on unit capacity that shortages of tractors and trailers will have. Thus, a good

Table 2.1

CRITICAL ITEMS FOR THEATER TMT CARGO COMPANIES

SRC		55018J410	55727L100
Design capacity (ston-km/day)[a] LIN		316,800	316,800
S70159	34 ton flatbed semitrailer	120	120
T61103	truck tractor	60	60

[a]Capacities of TMT Cargo Companies are usually expressed in short tons/day. We have multiplied those capacities by 160 kilometers, which according to FM 55-15 [6] is the length of line haul route segment that Theater TMT Companies are designed to service.

[2]The comments in this section apply equally well to other types of TMT companies, including Corps TMT Cargo Companies and TMT Petroleum Companies.

approximation to the unit's capacity may be obtained by ignoring ERC A items altogether and taking the critical items to be the ERC P items only. The resulting equation for estimating TMT company capacity is:

$$(2.4) \qquad CAP = DES * Min\{ FILL_{F34}, FILL_{TT} \}$$

where the subscripts should be interpreted as: F34 = 34 ton flatbed semitrailer; TT = truck tractor.

GS Ordnance Companies

General Support (GS) Ordnance Companies handle ammunition at Theater Storage Areas (TSAs) and Corps Storage Areas (CSAs) in a theater of operations. Handling ammunition involves receiving it (unloading trucks, barges, or trains that bring it to the site), storing it, and issuing it (loading it onto trucks or trains). Table 2.2 shows the items we feel are critical for units of this kind. The forklifts of all types are the only ERC P items in the TOEs for these units, but we have added the cranes to the critical item list as well. We have also added night-

Table 2.2

CRITICAL ITEMS FOR GS ORDNANCE COMPANIES

SRC Design Capacity (ston/day) LIN		09074H100 3696	09488L000 5322
F39378	Crane, wheel-mounted, 20 ton	6	6
N04456	Night-vision goggles	-	30
T48914	Diesel forklift, 6000 lb	-	10
T48941	Diesel forklift, 50,000 lb	4	4
T48944	Variable reach forklift, 6000 lb	10	-
T49255	Diesel forklift, 4000 lb	4	4
X50489	Electric forklift, 4000 lb	4	4
X50900	Electric forklift, 6000 lb	-	2

vision goggles. The Army has recently expressed concern that their effect on the capacities of these units is not properly considered. In addition, they illustrate one of the shortcomings of using Eq. (2.1) for estimating CSS unit capacity.

If we apply Eqs. (2.2) and (2.3), we will surely underestimate the capacities of these units. Suppose that the unit has 60 percent of the forklifts it requires and 100 percent of its cranes. The general method will estimate its actual capacity to be 60 percent of its design capacity.

But much of the ammunition-handling task can probably be performed by either a crane or a forklift. To be sure, it will be impossible to handle all loads with every piece of equipment. For example, the 50,000-lb forklift can lift an entire container full of ammunition, and the variable reach forklift is especially intended for unstuffing the containers. But if a unit has 60 percent of its forklift requirement, and 100 percent of its crane requirement, its capacity should be something between 60 and 100 percent of the design capacity. It should not be as low as 60 percent.

The designers of GS (and DS) Ordnance Company TOEs[3] assume that the capacities provided by cranes and forklifts can be added. Starting from a desired unit capacity to handle ammunition, they apportion it into an amount of ammunition best handled by crane and an amount best handled by forklift. They have planning factors that specify how much ammunition can be handled per day by a crane and by a particular kind of forklift. They divide the amount of ammunition best handled by crane by the planning factor for cranes to determine the required number of cranes, and they similarly calculate the forklifts required. To be consistent with their method for building the TOE, we should add the forklift and crane capacities to arrive at the total unit capacity.

An item on the critical list may not affect the whole capacity of the unit. For example, night-vision goggles would appear to affect the capacity of the unit only during the nighttime, and perhaps only during

[3]Force Development Directorate, Missile and Munitions Center and School, Redstone Arsenal, AL 35898.

dark, moonless, or overcast nights. Thus, even with no goggles on hand, the unit could have at least 50 percent of its design capacity.

The required number of an item on the critical list need not be the total number required by the entire unit. GS Ordnance Companies actually require 45 night-vision goggles, many more than we have shown in Table 2.2. The number in the table is the number of goggles required by the forklift and crane sections of the companies only. The remaining goggles are required in other sections--by company headquarters or the service section. We have assumed that only the forklift and crane sections must have the goggles in order for the unit to operate at full design capacity.

In view of these considerations, we propose the following simple procedure for estimating the capacity of a GS Ordnance Company from the on-hand inventories of the types of equipment in Table 2.2. Let

a_i = the tons/day of ammunition that can be handled by item i, where i is a crane or a forklift. These can probably be obtained from Force Development Directorate, Missile and Munitions Center and School, Redstone Arsenal.

$FILL_{NVG}$ = the ratio of on-hand to required night-vision goggles. The required number is the number required in the forklift and crane sections only. If the number on hand in the company exceeds this required number, set $FILL_{NVG}$ to 1.0.

Then we would estimate the actual capacity of the company to be:

$$(2.5) \qquad CAP = DES * \frac{1 + FILL_{NVG}}{2} * \sum_i a_i * FILL_i$$

where the summation includes terms only for cranes and forklifts but not for night-vision goggles.

Petroleum Supply Companies

Petroleum Supply Companies provide POL to TMT Petroleum Companies for delivery either to other Petroleum Supply Companies or to the petroleum platoons of Quartermaster Supply Companies. Quartermaster Supply Companies then distribute POL to local users--see next subsection. Petroleum Supply Companies also distribute a small amount of POL direct to local users. Table 2.3 lists the items that we feel belong on the critical item list. They are all in the supply sections of the company, and they are all directly involved in the storage of POL and in transferring POL into and out of storage. The fuel system supply point is the only LIN coded ERC P in the TOEs for these units.

It seems reasonable to combine the inventories of the two kinds of pumping assemblies and calculate a single FILL fraction for the pair, rather than computing separate FILL fractions for each. This implies that the two kinds of pumping assemblies can substitute for one another.

Table 2.3

CRITICAL ITEMS FOR PETROLEUM SUPPLY COMPANIES

SRC		10227H500	10427L000
Design Capacity (gal/day)		685,000	1,244,558
LIN			
E92641	Pressure assembly control	12	18
H52087	Filter-separator	24	48
J04717	Fuel system supply point	4	6
P97051	Pumping assembly, 350 gpm	40	54
P97119	Pumping assembly, 350 gpm	-	6
T12620	Collapsible tank, 20,000 gal	-	24
V12552	Collapsible tank, 10,000 gal	28	24
V15325	Collapsible tank, 50,000 gal	24	36

Similarly, we recommend combining the three kinds of storage tanks. The inventories should not merely be added, however. Instead, the storage capacities should be added, and a FILL fraction computed as the ratio of total gallons of storage capacity on hand to total gallons of storage capacity required. Thus two 10,000-gallon tanks can substitute for a

single 20,000-gallon tank, or a 50,000-gallon tank for two 20,000- and one 10,000-gallon tank. This leads to the following equations for estimating Petroleum Supply Company capacity. Let

$$(2.6)\qquad FILL_{STOR} = \frac{20*OH_{T20} + 10*OH_{T10} + 50*OH_{T50}}{20*RQR_{T20} + 10*RQR_{T10} + 50*RQR_{T50}}$$

$$(2.7)\qquad FILL_{PA} = \frac{OH_{PA1} + OH_{PA2}}{RQR_{PA1} + RQR_{PA2}}$$

$$(2.8)\qquad CAP = DES * Min\{ FILL_{PAC}, FILL_{FS}, FILL_{FSSP}, FILL_{STOR}, FILL_{PA} \}$$

where the subscripts are: PAC = Pressure assembly control, FS = Filter-separator, FSSP = Fuel system supply point, STOR = Storage, and PA = Pumping assembly.

We can test Eqs. (2.6)-(2.8) by comparing the two versions of Petroleum Supply Companies in the table. Thus, suppose we start with a company whose Standard Requirements Code (SRC) is 10427L000, and equip it with the inventories for a company with SRC 10227H500. Its actual capacity ought to be the design capacity of the SRC 10227H500 company. But when we calculate its actual capacity from Eqs. (2.6)-(2.8) (see Table 2.4), we get a somewhat different answer. In spite of this disagreement, we think it reasonable to calculate Petroleum Supply Company capacities using Eqs. (2.1)-(2.3), once the critical items from Table 2.3 have been combined as suggested above.

A better method for estimating Petroleum Supply Company capacity is unlikely to be simple. The Bulk Petroleum Study [7] critiques one other simple method for calculating the design capacity of a company with SRC 10427L000. The design capacity was calculated to be proportional to the inventory of pumps and to depend on no other equipment items. In

Table 2.4

APPLYING THE SIMPLIFIED METHOD TO
A PETROLEUM SUPPLY COMPANY, SRC 10427L000

Item	Required	On Hand	FILL
Pressure assembly control	18	12	0.67
Filter-separator	48	24	0.5
Fuel system supply point	6	4	0.67
Total pumping assemblies	60	40	0.67
Total storage, 000 gal	2520	1480	0.59
Minimum fill, Eq. (2.2)			0.5
Design capacity (gal/day)			1,244,558
Actual capacity, Eq. (2.3)			622,279
Design capacity of SRC 10227H500			685,000

effect, this assumes that the company is designed with an oversupply of all other equipment (notably storage). The same formula applied to a company with SRC 10227H500 fails to reproduce the stated design capacity of that unit.

Petroleum Platoons of Quartermaster Supply Companies

One of the missions of Quartermaster Supply Companies (also called Supply and Service Companies) is to supply bulk POL to local users, and one platoon in the company has that mission. A petroleum platoon has a storage/issue section with equipment similar to that of a Petroleum Supply Company (collapsible tanks, pumps, etc.), and a distribution section with trucks and tank semitrailers, and tank and pump units.

Table 2.5 shows the items we consider critical for performing the POL supply mission. None are coded ERC P in the TOE. The capacities come from the narrative portions of the TOE, and appear to reflect only the capacity of the distribution section to deliver POL to its customers. The storage and issue section must have the capacity to issue at least as much POL as the distribution section delivers, but it is not stated how much extra capacity it has to issue directly to users.

Table 2.5

CRITICAL ITEMS FOR PETROLEUM PLATOONS OF
QUARTERMASTER SUPPLY COMPANIES

SRC		29147H500	29147H520	42447L000
Design Capacity (gal/day)		39,300	81,900	81,000
LIN				
H52087	Filter-separator	2	6	4
J04717	Fuel system supply point	1	2	2
P97051	Pumping assembly	2	6	4
S73372	5000-gal tank semitrailer	5	9	9
V12141	Tank and pump unit, 1200 gal	2	5	5
V12552	Collapsible tank, 10,000 gal	6	12	12
X40794	Truck cargo	-	-	5
X40831	Truck cargo	2	5	-
X59326	Truck tractor	5	9	9

We propose to calculate the capacity of the platoon in two steps. First we calculate the effect on capacity of the equipment items used by the distribution section for delivering POL to its customers. Then we calculate the effect on capacity of the equipment items used for issuing POL by the storage and issue section to the distribution section. For simplicity, we assume there is no extra issue capacity, beyond that needed to supply the distribution section.

Two equipment sets can be used to distribute POL to users. The first consists of a 5000-gallon tank semitrailer hauled by a truck tractor, while the second consists of a tank and pump unit hauled by a truck cargo. Each equipment set can presumably be used independently of the other, so we apportion the design capacity of the platoon between these two sets in proportion to their capacities.

For companies with SRC 29147H500, there are five sets of the first kind with an aggregate storage capacity of 25,000 gallons, and two sets of the second kind with an aggregate capacity of 2400 gallons. Thus we apportion a fraction 25000/(25000 + 2400) or 0.912 of the platoon's capacity to sets of the first kind, and the remainder or 0.088 to sets of the second kind. For the other two SRCs in Table 2.5, the fractions

are 0.882 for sets of the first kind and 0.118 for sets of the second kind. Thus, the effect of distribution equipment on the platoon's capacity can be calculated as follows. First, we calculate FILL fractions for the two kinds of distribution equipment sets:

$$(2.9) \qquad FILL_{Set1} = Min\{ FILL_{TT}, FILL_{TST} \}$$

$$(2.10) \qquad FILL_{Set2} = Min\{ FILL_{TC}, FILL_{TPU} \}$$

where the subscripts are: TT = Truck tractor, TST = Tank semitrailer, TC = Truck cargo, and TPU = Tank and pump unit. Then we combine the two FILL fractions using the capacity fractions we calculated earlier. Thus,

$$(2.11) \qquad FILL_{Dist} = 0.912*FILL_{Set1} + 0.088*FILL_{Set2}$$

This applies to SRC 29147H500 only. For the other SRCs, one must replace the coefficients in Eq. (2.11) by the appropriate capacity fractions.

The rest of the equipment items in Table 2.5 are used by the storage and issue section, and we will assume that each of them is necessary for issuing POL. Thus, we calculate an overall FILL fraction for the issue-related equipment items according to:

$$(2.12) \qquad FILL_{Iss} = Min\{ FILL_{FS}, FILL_{FSSP}, FILL_{PA}, FILL_{CT} \}$$

where the subscripts are: FS = Filter-separator, FSSP = Fuel system supply point, PA = Pumping assembly, and CT = Collapsible tank.

Finally, we are in a position to calculate the capacity of the petroleum platoon as a whole:

$$(2.13) \quad CAP = DES * Min\{ FILL_{Dist}, FILL_{Iss} \}$$

Maintenance Companies

We have examined the maintenance companies shown in Table 2.6. Of all

Table 2.6

MAINTENANCE COMPANIES

SRC	Description
43007J200	Maintenance Co., Light Equipment, Division
43007J400	Maintenance Co., Light Equipment, Division
43007L000	Maintenance Co., Light Equipment, Division
43008J200	Maintenance Co., Heavy Equipment, Division
43008J400	Maintenance Co., Heavy Equipment, Division
43008L000	Maintenance Co., Heavy Equipment, Division
29209H900	Maintenance Co., Nondivisional
43209L000	Maintenance Co., Nondivisional
29134H200	Maintenance Co., Light Equipment, GS
43237J500	Maintenance Co., Light Equipment, GS
43637L100	Maintenance Co., Light Equipment, GS
43237J520	Second Shift, Light Equipment, GS
43637L200	Second Shift, Light Equipment, GS
29137H200	Maintenance Co., Heavy Equipment, GS
43238J500	Maintenance Co., Heavy Equipment, GS
43638L100	Maintenance Co., Heavy Equipment, GS
43238J520	Second Shift, Heavy Equipment, GS
43638L200	Second Shift, Heavy Equipment, GS

the types of units discussed in this section, the method of Eqs. (2.1)-(2.3) is least satisfactory for these. For one thing, a maintenance company does not have a single capacity; it has several. For example, the narrative section of the TOE for SRC 29137H200 (Maintenance Co., Heavy Equipment, GS) specifies capacities for

- Auto repair,
- Armament maintenance,
- Fire control repair,
- Fabric repair,
- Power generation equipment repair,
- Metal work, and
- Quartermaster/chemical equipment repair.

Other maintenance company TOEs specify even more kinds of capacity. Moreover, these capacities are specified in terms of maintenance man-hours that can be provided by people in particular military occupational specialties (MOSs). In fact, it is not common practice, except in certain special cases (e.g., where costly test, measurement, and diagnostic equipment--TMDE--is involved), to relate maintenance capacity to equipment at all.

That maintenance companies have multiple capacities follows from the variety of jobs they do. Each unit must be prepared to make many different kinds of repairs on many different kinds of equipment. Different repair jobs require people with different skills using different tools. Some skills and tools are useful for a wide variety of repair jobs, while others are more specialized.

It follows that few (if any) equipment items in a maintenance company will be "show stoppers." Therefore, the general method for calculating unit capacities (Eqs. (2.1)-(2.3)) definitely should not be used. However, a glance at the equipment items in the TOEs for these companies suggests how difficult it would be to devise a better simple method. The ERC A items include tool kits, welding sets, analyzers, and other instruments. It would require a significant effort to determine

which items are used for which kinds of jobs and which items can be substituted for which others.

In the absence of such a study, we offer a second general method. This one is more optimistic than the one described in Eqs. (2.1)-(2.3) in that no item is assumed to be a "show stopper." Rather, this method assumes that adding an item to a company's equipment inventory will always increase that company's capacity (or capacities). To avoid introducing a spurious bias in favor of buying one item over another, we assume that each dollar spent will add the same amount of capacity. Thus, we define:

p_i = the unit price of equipment item i (this can be obtained from the Army Master Data File (AMDF).

Then,

$$CAP = DES * \frac{\Sigma(p_i * OH_i)}{\Sigma(p_i * RQR_i)} \tag{2.14}$$

III. ESTIMATING COSTS OF LOGISTICS IMPROVEMENTS

This section describes a method for estimating the costs of the logistics improvements whose effects on logistics functional capacities were discussed in Sec. II. The improvements consist of the addition of equipment to CSS units such as DS or GS Ordnance Companies or TMT Companies.

The costs we wish to estimate, we should point out, are costs that the Army will incur in peacetime, and not costs that may be incurred during wartime activities. It is peacetime costs--costs for buying equipment and operating it in peacetime, costs for peacetime training, and so forth--that the Army estimates in putting together their budget submission. It is peacetime costs that are paid out of the budget passed by Congress.

The cost model method uses a model that estimates the nonrecurring and annual recurring costs of acquiring, maintaining, and operating an active Army unit in peacetime. Nonrecurring costs include procurement of the unit's equipment, procurement of extra equipment to serve as operational readiness and repair cycle floats, initial procurement of spares and repair parts for both the unit and central supply, initial training of personnel, etc. Annual recurring costs include replenishment spares and repair parts, military pay and allowances for the unit's personnel, a share of depot maintenance costs, etc. To estimate the cost of an improvement to a unit, we apply the cost model to descriptions of the unit before and after equipment is added and take the difference in estimated costs.

This model does not check whether the description of the unit makes sense. For example, if the user describes a unit as having equipment but no people, the cost model will nevertheless estimate costs for operating the unit. It is the responsibility of the user to provide unit descriptions that make sense.

The model uses cost factors and cost estimating relations based on historical data. Changes in how the Army does its day-to-day business (e.g., increased reliance on training with simulators or a reduced frequency of overhauls on major equipment items) may invalidate the factors and relations described here. (Inflation can render the cost factors obsolete as well, but we present a method for adjusting the model for inflation.) Thus, the factors and relations should be periodically reexamined and updated.

REQUIRED INPUTS

The cost model requires seven inputs:

- Aircraft procurement cost (Appropriation 2031),
- Missile procurement cost (Appropriation 2032),
- Wheeled and tracked combat vehicles procurement cost (Appropriation 2033),
- Other equipment procurement cost (Appropriation 2035),
- Equipment weight,
- Number of officers plus warrant officers, and
- Number of enlisted personnel.

In preparing the procurement cost inputs, we develop two inventories of LINs in the unit we are improving. We search the TAEDP file to find what equipment the unit is expected to possess at the point in time considered in our analysis. The inventories thus obtained form a base case. To form the second set of inventories we identify critical equipment items (see Sec. II) and add them to the unit, up to the required quantities specified in the unit's TOE. Finally, we extract unit prices from the AMDF, apply the prices to the items in the equipment inventories, and summarize by appropriation category. The appropriation category is not itself a data element in the AMDF, but it can be derived from the Materiel Category Code (MCC). For the CSS units we have dealt with in this study, most of the procurement is in the "Other" category.

Equipment weight is available in the AMDF, but we have been using a simple relation that estimates the equipment weight as 0.03 tons per million dollars of equipment procured.

The "M" Force, an extract from the FAS, contains three sets of personnel inventories for each Army unit. Each inventory contains numbers of officers, warrants, and enlisted personnel by year, for the same years as the TAEDP (assuming the two files are in phase). One inventory counts "structured strength," which we take to be the wartime requirement for personnel. The second inventory counts authorized strength, which we take to be the peacetime authorization. The third inventory counts projected on-hand personnel. The required number of personnel can also be obtained from the unit's TOE.

For our purposes, it hardly matters which personnel numbers we choose. In estimating the cost of a logistics improvement, the absolute number of personnel in the unit to be improved is not important. Only the change in the number of personnel is important. As explained in Sec. II, the improvements we consider do not change the number of personnel.

COST ELEMENTS AND COST FACTORS

The cost model consists of dozens of *cost elements*, most of which are estimated by multiplying one or more of the inputs by a *cost factor*. For example, military pay and allowances for officers (a cost element) are the product of the annual pay per officer (a cost factor) multiplied by the number of officers (an input). A few cost elements are estimated by slightly more complex formulas, as we describe below.

We obtained the cost factors from two sources: the *U.S. Army Force Planning Cost Handbook (AFPCH)* [8], the latest edition of which appeared in 1982; and the *U.S. Army OMA and MPA Cost Factors Handbook* [9], last updated in 1984. We have adjusted the factors to reflect 1985 price levels. If the user wishes the model to reflect price levels for a different year, he must further adjust the factors. We assume that the four procurement cost inputs will reflect the price levels for the user's chosen year, so factors that multiply the procurement cost inputs

need no adjustment. Cost factors that multiply numbers of personnel should be adjusted by an inflation factor that depends on the appropriation category to which the cost element belongs. The user will need inflation factors for three appropriation categories: ammunition procurement, military pay and allowances (MPA), and operations and maintenance, Army (OMA).

We separate the costs estimated by the cost model into *investment* and *operating* costs. Investment costs are costs that must be met from the investment appropriation categories, which include the equipment procurement accounts mentioned above (2031, 2032, 2033, and 2035), plus the ammunition procurement account (2034). Operating costs are met from the MPA account (Appropriation 2010) and from the OMA account (Appropriation 2020).

Investment and operating costs are each further separated into *direct* and *indirect* costs. The direct costs are those directly associated with the unit whose cost is being estimated. The indirect costs are those incurred by other parts of the Army, but attributable to the unit's existence and activities.

Direct Investment Costs

The direct investment cost elements, and the cost factors by which we estimate them, are shown in Table 3.1. Each nonempty cell in the table corresponds to a cost element. All the factors in this table except those for ammunition procurement are applied in one way or another to the model's equipment procurement inputs. Thus it is not necessary to adjust them for price changes.

For each appropriation category except ammunition, the nonrecurring cost for major equipment is an input to the model. The recurring cost for major equipment, which covers peacetime losses of equipment, is the factor in the table multiplied by the nonrecurring cost of major equipment. Likewise, the operational readiness float, repair cycle float, and nonrecurring repair parts/secondary items cost elements are calculated as the factor in the table multiplied by the nonrecurring cost of major equipment. The annual recurring cost for repair

Table 3.1

DIRECT INVESTMENT COST ELEMENTS AND FACTORS

	Non-Recurring	Annual Recurring
Aircraft Procurement (2031)		
Major equipment	[a]	0.025
Operational readiness float	0.085	--
Repair cycle float	0.046	--
Repair parts/secondary items	0.11	0.03
Missile Procurement (2032)		
Major equipment	[a]	0.0005
Operational readiness float	0.02	--
Repair cycle float	0.055	--
Repair parts/secondary items	0.09	0.02
Missiles	[b]	[b]
Wheeled & Tracked Combat Vehicle Procurement (2033)		
Major equipment	[a]	0.008
Operational readiness float	0.054	--
Repair cycle float	0.057	--
Repair parts/secondary items	0.08	0.03
Ammunition Procurement (2034)		
Ammunition, $/person	1.	143.
Other Equipment Procurement (2035)		
Major equipment	[a]	0.014
Operational readiness float	0.036	--
Repair cycle float	0.023	--
Repair parts/secondary items	0.07	0.038

[a] Input to the model.

[b] Throughput. It is entered by the user and appears unchanged as part of the output.

parts/secondary items is calculated as the factor in the table multiplied by the *sum* of the nonrecurring costs for major equipment, operational readiness float, and repair cycle float.

Missile equipment includes missile launchers and associated equipment, but does not include the missiles themselves because missiles are not specified as unit equipment in TOEs. Thus the nonrecurring and recurring costs of the missiles appear as additional cost elements. They are not, however, calculated in the model. Rather, the user must enter the costs directly and the model will simply display them unchanged in the output. This should not be a problem for CSS units, since these units do not have missiles or missile-related equipment.

The ammunition cost elements cover the cost of ammunition consumed during training in the unit. For CSS units, this will be mostly small arms ammunition. The factors in the table are expressed as dollars per person and must be multiplied by the total number of people in the unit to obtain the values for these cost elements. These cost factors must be adjusted for price changes using the ammunition procurement inflation factor.

Indirect Investment Costs

The only indirect investment costs we identify are the costs of ammunition for MOS training. The nonrecurring cost is $380 per person, whereas the recurring cost is $85 per person per year. These factors apply to a "typical" Army unit. For a CSS unit, these cost factors should probably be much lower. However, these cost elements typically constitute only a small fraction of the total cost of the unit. These cost factors must be adjusted for price changes by using the inflation factor for the ammunition procurement appropriation category.

Other indirect investment costs can readily be imagined. For example, a new unit might require a new Army base or new depot facilities. The cost model now assumes that there is room for the unit at an existing base and that the appropriate kinds of facilities exist at the current depots. If these assumptions are violated in a particular instance, the appropriate additional cost elements would have to be estimated.

Direct Operating Costs

The cost factors for estimating the direct operating cost elements are shown in Table 3.2. The Permanent Change of Station (PCS) cost elements for officers are estimated as follows. The nonrecurring cost is the sum of the nonrecurring cost factors per officer and the cost per officer move, multiplied by the number of officers (including warrant officers). The annual recurring cost is estimated in the same way, except that it uses the cost factors from the "annual recurring" column of the table, and the officer-moves factor is multiplied by the officer rotation rate. This accounts for our assumption that only a fraction (35 percent, according to the table) of officers in a unit will be replaced each year. The PCS cost elements of enlisted personnel are estimated in an analogous way, using the factors for enlisted men in place of those for officers.

Table 3.2

DIRECT OPERATING COST FACTORS

	Non-Recurring	Annual Recurring
Military Pay and Allowances (MPA) (2010)		
PCS, $/officer	5900	900
PCS, $/officer move	9300	9300
Officer rotation rate	--	0.35
PCS, $/enlisted man	1900	4900
PCS, $/enlisted move	2400	2400
Enlisted rotation rate	--	0.5
Pay & allowances, $/officer	--	48700
Pay & allowances, $/enlisted man	--	21300
Operating and Maintenance, Army (OMA) (2020)		
Minor equipment	0.019	--
PLL repair parts	0.0382	--
Org. clothing & equip, $/person	830.	--
Unit operating cost, $/person	--	1000.
Non-aircraft operating factor	--	0.026
Aircraft operating factor	--	0.02

Pay and allowances are annual recurring costs, and hence do not give rise to nonrecurring cost elements. The recurring costs are estimated as the product of the factor from the table multiplied by the number of officers or enlisted men, as appropriate.

The cost factors for PCS and for military pay and allowances must be adjusted for price changes by using the inflation factor for the MPA appropriation category.

The minor equipment cost is entirely a nonrecurring cost. It is the product of the factor from the table multiplied by the sum of the four procurement cost inputs to the model, namely aircraft procurement, missile procurement, wheeled and tracked combat vehicle procurement, and other equipment procurement. The cost for the Prescribed Load List (PLL), also a nonrecurring cost, is the product of the factor from the table multiplied by the sum of the four procurement cost inputs plus the minor equipment cost.

The organizational clothing cost is nonrecurring and is calculated as the product of the factor in the table and the total number of people (officers plus enlisted personnel) in the unit. This cost must be adjusted for price changes using the OMA inflation factor.

The cost of unit operations, a recurring cost, consists of three terms. The first term is the product of the total personnel and the Unit Operating Cost factor from the table. This term must be adjusted for price changes using the OMA inflation factor. The second term is the cost of operating all equipment except for aircraft. It is calculated as the product of the non-aircraft operating factor and the sum of three of the four procurement cost inputs to the model (all but the aircraft procurement cost). The third term is calculated as the product of the aircraft operating factor multiplied by the aircraft procurement cost input. The terms that depend on equipment costs need not be adjusted for price changes, because we assume the user has adjusted the procurement costs prior to providing them as inputs to the model.

Indirect Operating Costs

The cost factors for estimating the indirect operating cost elements are shown in Table 3.3. There are both nonrecurring and annual recurring cost elements for MOS training. They are calculated as the product of the appropriate factor from the table multiplied by the number of officers or enlisted men in the unit, as appropriate. These costs must be adjusted for price changes using the MPA inflation factor.

Each of the nonempty cells in the OMA section of the above table gives rise to a cost element. The Program 7S, $/ton factor is applied to the equipment weight and represents the cost of initially deploying the equipment to its peacetime station. It must be adjusted for price changes using the OMA inflation factor. The Program 7M factor is applied to the four equipment procurement costs provided as inputs to

Table 3.3

INDIRECT OPERATING COST FACTORS

	Non-Recurring	Annual Recurring
Military Pay and Allowances (MPA) (2010)		
MOS training, $/officer	10000	6350
MOS training, $/enlisted man	8800	2500
Operating and Maintenance, Army (OMA) (2020)		
Prog. [illegible] Base operations, $/person	--	4000
Prog. 7S [illegible] supply, $/person	3280	1950
Prog. 7S, [illegible] supply, $/ton	0	--
Prog. 7M, Depot maintenance	--	0.018
Prog. 8M, Medical, $/person	60	350
Prog. 8T, Training, $/person	1540	940
Prog. 8O, Other, $/person	1550	520
Prog. 9, $/person	--	0

the model. This cost covers the share of depot maintenance attributable to the unit whose cost is being estimated. Because this factor is applied to procurement costs, which we assume are already adjusted for inflation, no further adjustment of this cost factor is necessary.

All the other factors in the OMA part of the table are costs per person and must be applied to the total personnel in the unit. They must be adjusted for price changes using the OMA inflation factor.

PRESENTATION OF OUTPUTS

The various ways of presenting output from this model are merely different ways of summarizing the cost elements. Ultimately, the best way to summarize and present the output will depend on the points one wishes to illustrate, but here are some suggestions. One might summarize the cost elements the way we described the model: direct investment, indirect investment, direct operating, and indirect operating. Or one might summarize them by appropriation category. Other possible summarizations are described in Ref. 10. Whatever summarization is used, we recommend reporting nonrecurring costs separately from annual recurring costs.

Sometimes it is useful to present a single cost index that can be used for quick comparisons of alternatives. The Army uses life-cycle cost as such an index. It is calculated as the total nonrecurring cost plus a specified number of years' worth of the total annual recurring cost (the Army often uses 20 years). We stress that this is useful for quick, rough comparisons only. It should be used in addition to, and not in place of, more detailed presentations of the model's outputs.

ESTIMATING THE COST OF A LOGISTICS IMPROVEMENT

In the POLA project, we wish to use the model to estimate the incremental cost of improvements to CSS units. When the improvement consists only of adding equipment to a unit, we estimate the cost by two applications of the model. We estimate the total cost of the unit before the equipment is added, and again after adding the equipment. The cost of the improvement is the difference between the "before" and "after" cost estimates. Each cost element can be differenced separately, and these differences can be summarized and presented in any desired way.

If the improvement consists of replacing old kinds of equipment with new kinds (e.g., an old type of forklift with a new, more capable one), the cost of the improvement can no longer be estimated in this way. To do so assumes that the nonrecurring costs associated with the displaced old equipment can be fully recovered and used to offset the costs associated with the new equipment. This may be partly true, if the equipment can be sold (e.g., for salvage or to a foreign government). However, the income from such sales may not benefit the Army, and perhaps should not be counted.

A similar problem exists regarding people. If the new equipment requires fewer people to operate it than did the old equipment, the unit may give up people. Differencing the "before" and "after" costs implicitly and wrongly assumes that one can recover the nonrecurring costs associated with these personnel (e.g., costs of initial MOS training).

Even for the personnel who are not given up, the nonrecurring costs may not be entirely applicable to the new situation. The model assumes that they can switch to operating the new equipment with no greater training costs than they would have incurred in the normal course of peacetime operations with the unit. This might be the case if the old personnel were displaced by new, differently trained ones only as fast as personnel would normally be rotated through the unit. However, if some form of extra transitional training is needed, a new cost element should be added to the model to reflect it.

The recurring costs of the old equipment and of personnel given up by the unit need not be borne. However, to develop a full accounting of the cost of a logistics improvement, one should specify the disposition of the displaced personnel and equipment. If the old equipment is declared surplus and disposed of, the Army will incur no recurring costs. If the equipment is placed in Central Supply as an addition to war reserves, the Army will have to pay a nominal cost to maintain the equipment in mothballs. However, if the equipment is transferred to another unit, the recurring costs will have to be borne after all. Similar comments apply to the displaced personnel.

In general, to estimate the cost of an improvement, one must properly account for "sunk" (i.e., unrecoverable) costs, and one must include all aspects of the Army that will be affected by the improvement. In the first case, where the improvement consisted entirely of adding equipment to a unit, the same "sunk" costs were present in both the "before" and "after" versions of the unit. In addition, the single unit receiving the equipment was the only part of the Army affected. In the second case, some of the "sunk" costs in the "before" version were not present in the "after" version. Blindly differencing total "before" and "after" costs leads to wrongly taking a credit for these "sunk" costs. Also, the dispositions of the old equipment, and of any personnel given up by the unit, might affect other parts of the Army.

POSSIBLE EXTENSIONS TO THE MODEL

The cost model described above would be made more useful if it were extended in either or both of two directions.[1] The easier extension would provide versions of the model for Reserve and National Guard units. The more difficult extension would spread the costs estimated by the model over time, to reflect the time-phased impact of an improvement on the Army's annual budgets.

Model Versions for Reserve and National Guard Units

The cost model currently estimates costs for active units only. The same model, with the same cost elements, should work equally well for Reserve or National Guard units, but it would require different cost factors. These factors have yet to be developed.

The Reserve and Guard versions of the model would have somewhat different appropriation categories. All the procurement categories would remain the same, but the Reserve and National Guard have their own separate MPA and OMA appropriation categories. These are shown in Table 3.4.

[1]The Arroyo Center does not contemplate making these extensions as part of the POLA project. However, we anticipate making both of these extensions as parts of other, future Arroyo Center projects.

Table 3.4

MPA AND OMA APPROPRIATIONS BY COMPONENT

	Active Army	Army Reserve	National Guard
MPA	2010	2070	2060
OMA	2020	2080	2065

A Time-Phased Cost Model

The cost elements estimated by the model can be spread over actual fiscal years to provide estimates of the effect of a proposed logistics improvement on the Army's budget. The user would first have to specify a schedule for making the improvement--that is, specify, year by year, how many new equipment items and personnel would be added to the unit, and how many old equipment items and personnel retired.

The model would estimate time-phased costs in two steps. In the first step, it would spread nonrecurring costs over time to coincide with the deliveries and withdrawals of equipment and personnel. It would estimate the recurring costs in any year from the average equipment and personnel inventories for that year. This time phasing of costs corresponds to an artificial currency we call *delivery dollars*, which is useful only for modeling or analysis purposes.

In the second step, the time phasing of the delivery dollars would be adjusted to approximate the time-phased requirements for *budget authority*. Budget authority (sometimes called obligational authority) is approximately the currency in which the Army budget is expressed. Not all actions in a particular year are funded by the budget for the same year. Some actions that occur in one year are paid for out of a different year's budget. *Funding profiles* can be developed that capture the distribution over years of budget dollars used to finance a requirement for delivery dollars in a particular year. There should be separate funding profiles for each appropriation category--for example, procurement, MPA, and OMA appropriations.

IV. DEFINING CASES FOR ANALYSIS

In this section we discuss the construction of cases for analysis. For each case we must develop inputs for LDM and the cost model. One case will be singled out as a reference, or *base case*. Combat performance measures (estimated by LDM) and costs (estimated by the cost model) for the other cases will be compared to those from the base case.

Preparing cases involves three steps. First, one must identify the CSS units to be considered in the analysis. These must be units that contribute to the logistics functional capacities represented in LDM that deploy to the theater of operations considered in the analysis.

Second, one must describe each unit identified. The description will include quantities needed for input to both LDM and the cost model. Units must be described as they appear in the base case and as they may appear in other cases--for example, with logistics improvements.

Finally, one must combine the unit descriptions into overall case descriptions. All the units will appear in every case, but some will appear in their initial, unimproved state and some in an improved state. Potentially, a different case is generated by improving each possible subset of units--altogether an astronomical number. We present a systematic way to generate sequences of cases, in which units contributing to the same logistics functional capacity are improved one by one in the order in which they arrive in the theater of operations. These sequences consist of only a small fraction of all possible cases.

This method of generating cases is suitable so long as the improvement to one unit does not affect other units. This condition is satisfied when improvements consist only of adding equipment to a unit. It is not satisfied when there are improvements that consist of replacing old equipment types with new, more capable types, for then the displaced equipment may be distributed to other units. We have not worked out a scheme for redistributing displaced equipment, but later we will discuss some features that such a scheme should have (see the subsection on "Logistics Improvements Affecting Multiple UICs").

We have carried out these three steps for a sample analysis using many small, unintegrated computer programs and much manual labor. As LEA's Logistics Net Assessment System [5] matures, we expect the agency will develop methodology components that largely automate each of these steps and tie them together into an integrated system for preparing cases. LEA has already accomplished considerable work in this direction.

IDENTIFY CSS UNITS

The first step in defining analysis cases is to identify which CSS units will be considered to receive logistics improvements in the analysis. By this we do not mean types of units, but actual individual units. Each such unit is identified by its Unit Identification Code (UIC). These must be units that deploy to the theater of operations in the scenario used for the analysis. They must also be units that perform logistics functions that are represented in the Logistics Decision Model (LDM).

All the UICs in the Army are listed in the "M" Force, an extract from the FAS. If the standard NATO scenario is used for the analysis, the Army Deployment Control Code (ADCCO), a data element in the FAS, can be used to determine which UICs will deploy to the theater and when they will do so. For other scenarios, the user must locate his own source of information for determining which UICs to include in the analysis.

In Ref. 3, where we show how to represent selected logistics functions in the LDM, we identify units that provide different kinds of logistics capacities by their SRCs. In Table 4.1, we list these SRCs, partitioned into logistics functions considered in LDM support structure described there. We wish to include in the analysis only UICs that have one of these SRCs, or a variant thereof. (For example, we found a DS Ordnance Company in the "M" Force with an SRC of 09487L031, which is a variant of the SRC 09487L000.)

Depending on exactly how the LDM support structure has been formulated, it may be that not all UICs in a functional group correspond to the same LDM input parameter. For example, GS Ordnance Companies

Table 4.1

FUNCTIONAL CATEGORIES OF SRCS

Category Name	SRC	Category Name	SRC
DS Ordnance Co.	09064H100	Maint. Co., Light	43007J200
	09487L000	Equipment Division	43007J400
			43007L000
GS Ordnance Co.	09074H100		
	09488L000	Maint. Co., Heavy	43008J200
		Equipment Division	43008J400
Corps TMT Cargo Co.	55023J410		43008L000
	55728L100		
		Maint. Co.,	29209H900
Theater TMT Cargo Co.	55018J410	Nondivision, DS	43209L000
	55727L100		
		Maint. Co., Light	29134H200
Trailer Transfer Point	55540H5GE	Equipment, GS	43237J500
	55540LE00		43637L100
Petroleum Supply Co.	10227H500	2nd shift	43237J520
	10427L000		43637L200
Petroleum Platoon of	29147H500	Maint. Co., Heavy	29137H200
QM Supply Co.	29147H520	Equipment, GS	43238J500
	42447L000		43638L100
TMT Petroleum Co.	55018H620	2nd shift	43238J520
	55018H650		43638L200
	55728L200		

operate both Theater Storage Areas (TSA) and Corps Storage Areas (CSA). It might be necessary to assign each UIC to one or the other of these types of storage facility. In this case, the UICs in a functional group would have to be further subdivided. If the analysis is using the standard NATO scenario, the third position of the ADCCO, the Force Analysis Simulation of Theater Administrative Logistics Support (FASTALS) logical region, may help the user perform this subdivision. (Recall that the ADCCO is a data element in the FAS.) The FASTALS model [11] is used by the U.S. Army Concepts Analysis Agency (CAA) in a variety of studies. Given a combat force and the workloads it generates in a wartime scenario, FASTALS determines what CSS units are required

for support. These CSS units are laid down on a crude map of the theater. Logical regions are areas on this map; in increasing order of distance from the FLOT, they are Division, Corps, Rear Corps Zone (RCZ), Communications Zone (COMMZ), Port, and Offshore.

DESCRIBE EACH UIC

Next, we must describe each of the UICs selected above, both as it appears in a reference or base case and as it will appear if it receives logistics improvements. We recommend that each UIC be improved by filling items of equipment on its critical items list (see Sec. II) to their required inventories. This will increase its capacity to the design capacity for that kind of unit. Although one could fill requirements only partially, we do not think these additional options will add significantly to the value of the analysis.

At the least, the description of a UIC in either its initial or improved state must consist of the inputs needed by both LDM and the cost model, as shown in Table 4.2. For LDM we need the capacities of the units, the times at which those capacities enter the theater of operations, and the LDM capacity parameter to which the unit

Table 4.2

UIC DESCRIPTORS

Descriptor	Initial State	Improved State	Input for
Capacity	Actual	Design	LDM
Latest arrival date			LDM
LDM capacity parameter			LDM
Procurement costs of:			
Aircraft equipment	On hand	Required	Cost
Missile equipment	On hand	Required	Cost
WTCV equipment	On hand	Required	Cost
Other equipment	On hand	Required	Cost
Equipment weight	On hand	Required	Cost
Total officers (incl. warrant)			Cost
Total enlisted personnel			Cost

contributes. If the analysis uses the standard NATO scenario, the Latest Arrival Date (LAD), available from positions 4-6 of the ADCCO, provides the time a unit is scheduled to enter the theater. Section III discusses the inputs needed by the cost model. Of course, the user should also keep track of the individual equipment items added to or displaced from each UIC to improve it.

The differences between the inputs in the initial and improved states are that in its improved state the unit has its design capacity and procurement costs for the required inventories of the critical equipment items. In its initial state the unit has its actual capacity and procurement costs of the on-hand inventories of the critical equipment items. The unit will have the same inventories of noncritical equipment items and personnel in the two states, and it is unimportant whether they are the required or on-hand inventories. We also assume that the unit, whether improved or not, will arrive in the theater at the same time and contribute to the same LDM capacity parameter.

CONSTRUCT ANALYSIS CASES

To construct an analysis case, we select a subset of UICs to improve and leave the remaining UICs in their initial, unimproved states. We identify one of these cases as a reference, or *base case*, usually the case in which the UICs are all in their initial states.

A case's input to LDM will appear in the TIME_PHASE file [2,3]. The capacity of a particular UIC will appear there as an increment to the appropriate LDM capacity parameter at the arrival time specified.

The cost model can be applied to each UIC individually, or it can be applied to any partitioning of the UICs. (A partitioning is a separation of the UICs into groups such that each UIC appears in one and only one group.) A convenient partitioning can be formed by grouping together all UICs that affect the same LDM capacity parameter.

For each case, one prepares the cost model inputs for a group of UICs by accumulating the cost model inputs over all UICs in the group, taking care to use the inputs for the appropriate state (improved or initial) for that UIC in that case. One calculates the cost of

improvements to the UICs in a group for a particular case by applying the cost model first to the inputs for that case, then to the inputs for the base case, and finally taking the differences between the two sets of costs thus estimated. The cost of improvements in the base case is therefore zero.

In any analysis, there are likely to be dozens of UICs. Since a different case results when one improves any subset of the UICs, the number of possible cases is astronomical. They cannot all be investigated. The following method will generate a manageable number of interesting cases with which to begin the analysis.

We construct a separate sequence of cases for each LDM capacity parameter for which we have identified UICs. Each sequence begins with the base case, in which all UICs appear in their initial, unimproved states. To form the rest of the sequence, we sort the UICs corresponding to the chosen LDM capacity parameter according to LAD. If two UICs have the same LAD, we sort them according to the ratio of capacity added in the improved state to the procurement cost of the added equipment. A UIC with a higher ratio will precede one with a lower ratio. The first excursion case will improve only the first UIC--that is, the one with the earliest LAD, and in case of units with the same LAD, the UIC with the largest ratio. The second excursion case will improve the first and second UICs. And so on. Throughout the sequence, all UICs that do not correspond to the chosen LDM capacity parameter will remain in their initial, unimproved states. The LDM cases in the sequence successively increase the chosen LDM capacity parameter while holding all other capacity parameters at their base case values.

This scheme tends to add capacity early in the simulation, so it can influence combat performance for a longer period and therefore have the greatest cumulative benefit. However, the capacity added early might conceivably be more costly than capacity added late. Thus, there is no guarantee that this is the optimal order in which to improve the UICs. We nevertheless recommend this order because it would be difficult to find an order that would always do better.

As the analysis progresses, it may prove desirable to increase two or more capacity parameters simultaneously. This can be accomplished by combining the sequences of cases described above. Instead of improving UICs corresponding to only one LDM capacity parameter, one improves UICs corresponding to several. But one would always improve the UICs corresponding to the same LDM capacity parameter in the order described above.

LOGISTICS IMPROVEMENTS AFFECTING MULTIPLE UICS

The above method for defining analysis cases is suitable so long as improvements to a UIC consist only of adding equipment. But one might also improve a UIC by replacing its old equipment with new, more capable types. In Sec. III, while discussing how to estimate the cost of such an improvement, we mentioned that the displaced equipment might be given to other UICs considered in the analysis. Thus, a scheme for distributing displaced equipment to other UICs might be a worthwhile addition to the POLA methodology. We have not worked out such a scheme ourselves, but the following considerations should govern its design.

First, some types of equipment may be critical for several different kinds of units, corresponding to different LDM capacity parameters. The scheme should allow the user to specify which parameter he wishes to favor. One option should be to distribute the equipment only to UICs that contribute to the same LDM parameter as did the UIC from which the equipment is displaced.

Second, UICs should be sorted in a priority order. In the above discussion, we gave higher priority to UICs that enter the theater early. Other things being equal, UICs with higher priority ought to receive displaced equipment before UICs with lower priority.

But other things may not be equal. How much an equipment item will affect a UIC's capacity will depend on other critical equipment items in the same UIC. Adding an equipment item may have no effect, if some other item is already a "showstopper." The equipment distribution scheme should include an option to distribute each kind of equipment independently of others, strictly according to the priority scheme. But

one should also consider options to distribute equipment with the goal of maximizing the incremental capacity achieved. It is not clear how to trade off adding some capacity early versus adding more capacity later.

Finally, if the scheme is capable of distributing displaced equipment, in principle it can also redistribute the equipment that the UICs possess in their initial, unimproved states. The Logistics Readiness Rating Report (LR^3), prepared periodically by the Logistics Plans and Analysis Division of LEA, suggests that units' readiness ratings as defined in AR 220-1 could be improved merely by redistributing equipment already on hand in these units. It is likely that redistribution of equipment could increase logistics functional capacities as well, as estimated by the methods outlined in Sec. II. In any event, the possibility is worth investigating, and could be investigated if an appropriate equipment distribution scheme were developed.

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